How well can we establish baryon resonances ?

Basic Question

To which extend can the scattering data tells us about the actual existence of a resonance?

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Resonance: as a pole of the scattering amplitude in the complex energy-plane

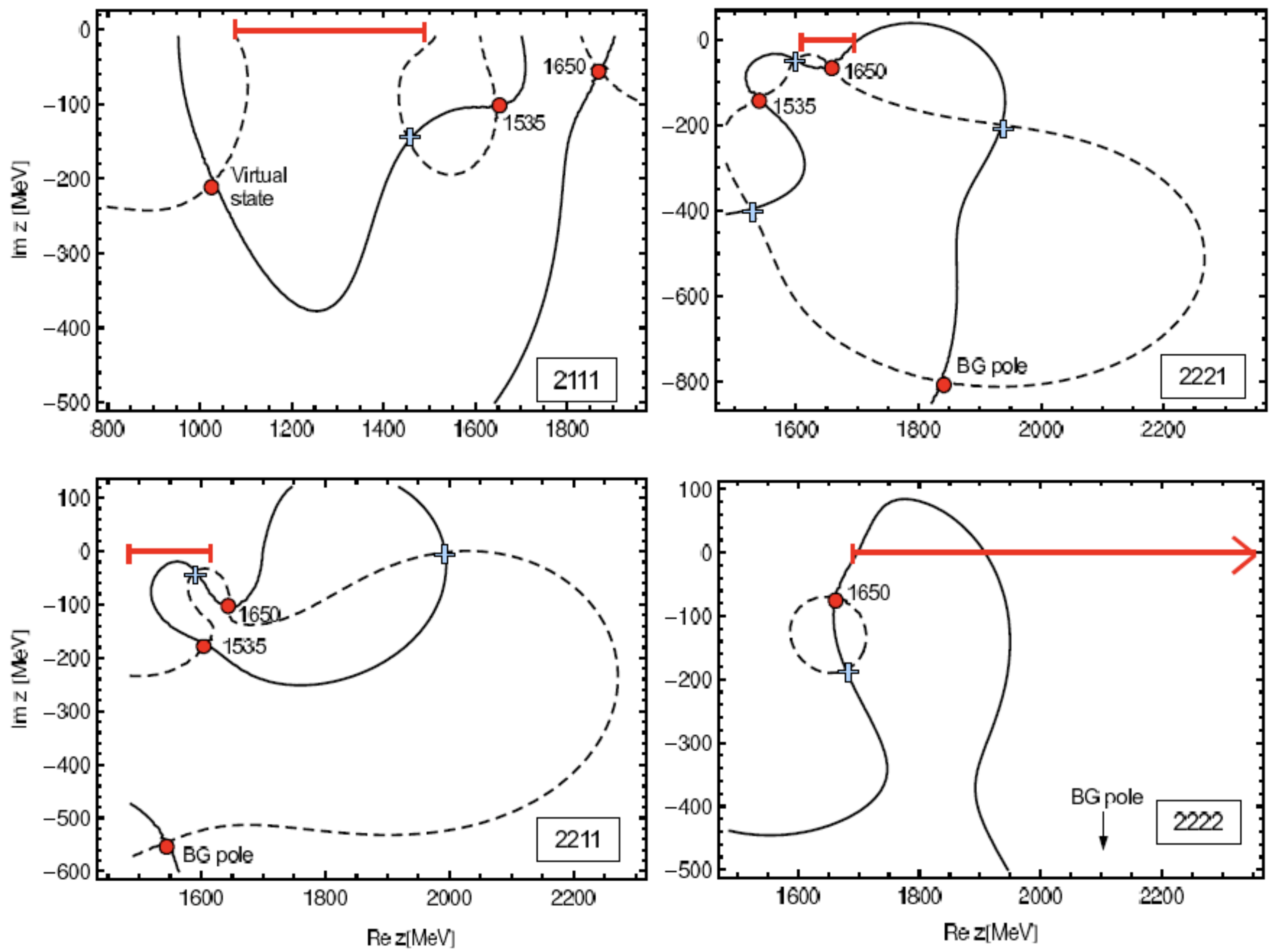
❑ Resonances should be associated with the poles of the scattering amplitude in the complex energy-plane.

- The threshold of a given MN channel is a branch point which leads to different Riemann sheets
  - For a stable MN channel, the branch point is located on the real axis and leads to two Riemann sheets.
  - For an unstable MN channel, the branch point is in the complex plane (complex branch point) .
- The poles can be located on all sheets. Depending on the sheet, their influence on the amplitude on the real (or physical) axis are different. For stable MN channels, poles located on the:
  - First (physical) sheet wrt the MN channel are bound states wrt that channel.
  - Second (unphysical) sheet wrt the MN channel with their real parts below threshold are virtual states.
  - Second (unphysical) sheet wrt the MN channel with their real parts above threshold are resonances.
  - Higher (unphysical) sheets can also influence the amplitude on the physical axis.

For unstable MN channels ($\sigma N, \rho N, \pi\Delta$), resonances are in the second sheet wrt $\pi\pi N$ threshold.

Example: *Poles in the S_{11} πN amplitude*

(Doring & Nakayama, EPJA'10)



	Position [MeV]	$g_{\pi^- p}$
Sheet 2111		
VS	$1031 - 203\,i$	$-0.51 + 1.58\,i$
$N^*(1535)$	$1647 - 103\,i$	$-1.55 + 1.40\,i$
$N^*(1650)$	$1872 - 57\,i$	$0.91 + 2.64\,i$
Sheet 2211		
$N^*(1535)$	$1608 - 175\,i$	$3.35 + 1.82\,i$
$N^*(1650)$	$1645 - 105\,i$	$-1.83 + 1.88\,i$
BG	$1545 - 545\,i$	$-0.78 + 3.52\,i$
Sheet 2221		
$N^*(1535)$	$1538 - 139\,i$	$1.42 + 0.46\,i$
$N^*(1650)$	$1655 - 59\,i$	$-0.89 + 0.48\,i$
BG	$1837 - 800\,i$	$0.31 + 2.39\,i$
Sheet 2222		
$N^*(1535)$	no pole	
$N^*(1650)$	$1662 - 72\,i$	$-1.03 + 0.12\,i$
BG	$2129 - 1289\,i$	$0.33 + 2.26\,i$

——— Re[T]=0

- - - - Im[T]=0

red line: part of the physical axis directly connected to the respective sheet.

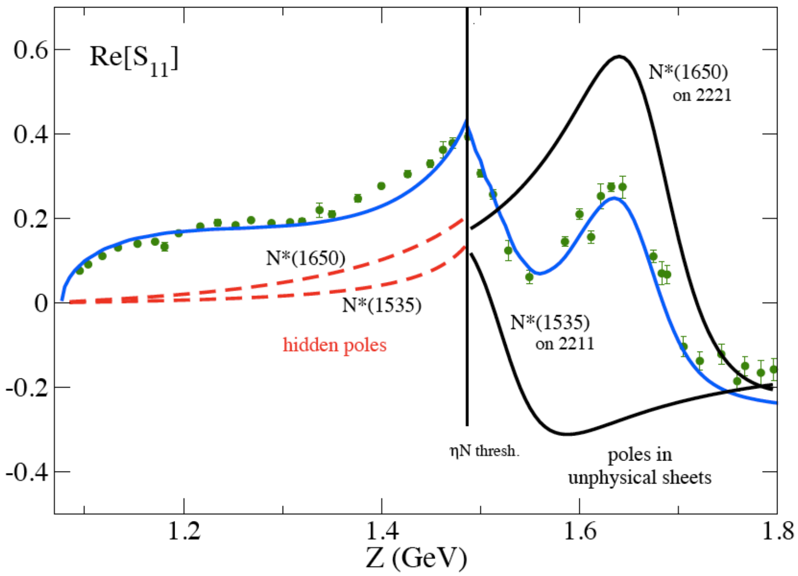
Notation:

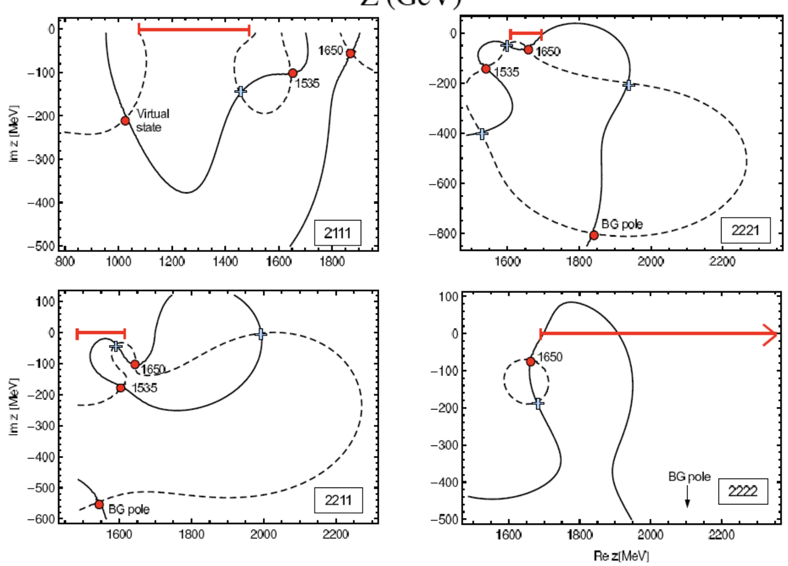
$\begin{cases} 1 \rightarrow G^{(1)}(z) \\ 2 \rightarrow G^{(2)}(z) \end{cases}$ e.g. $\begin{cases} \text{2111: unphysical wrt } \pi N\text{, physical wrt others} \\ \text{2211: unphysical wrt } \pi N \& \eta N \text{ physical wrt } K\Lambda \& K\Sigma \end{cases}$

Example: Poles & Shape of the S_{11} πN amplitude

(Doring & Nakayama, EPJA'10)

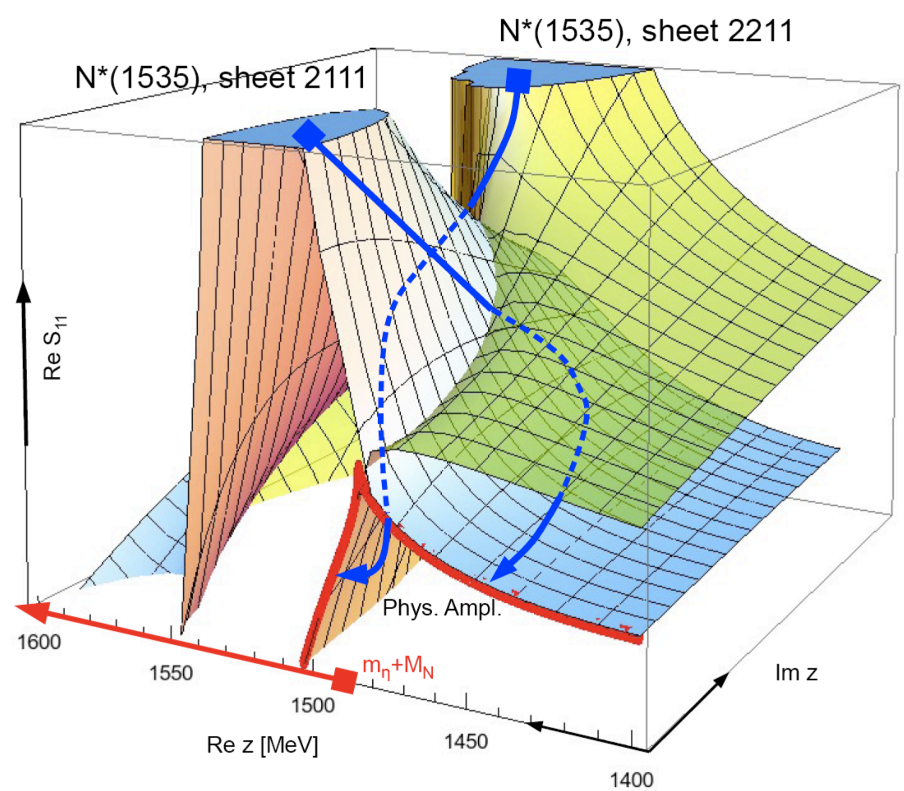
Re[S_{11}] πN ampl.





---- hidden N*(1535) & N*(1650)

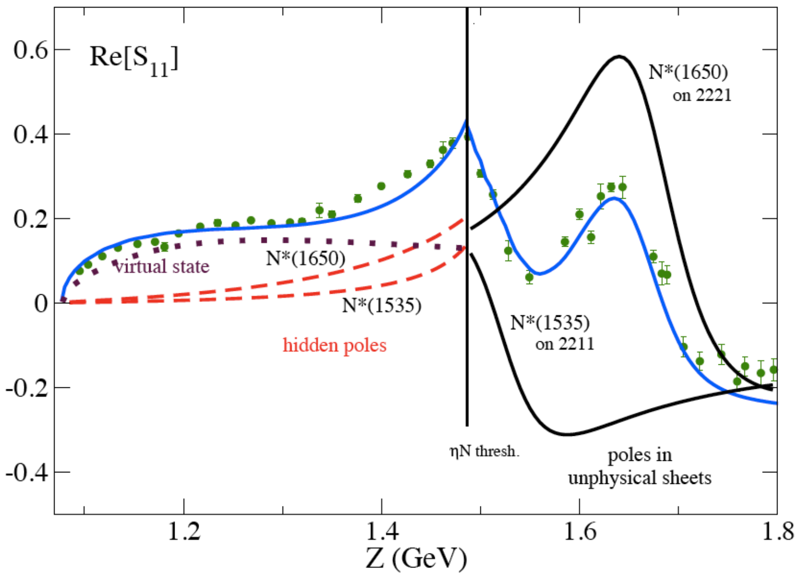
—— $T^{(i)}_{\rm PA} = \sum_j \frac{a^j_{-1}}{z - z^j_0}$ i=2211,2221 ; j=poles

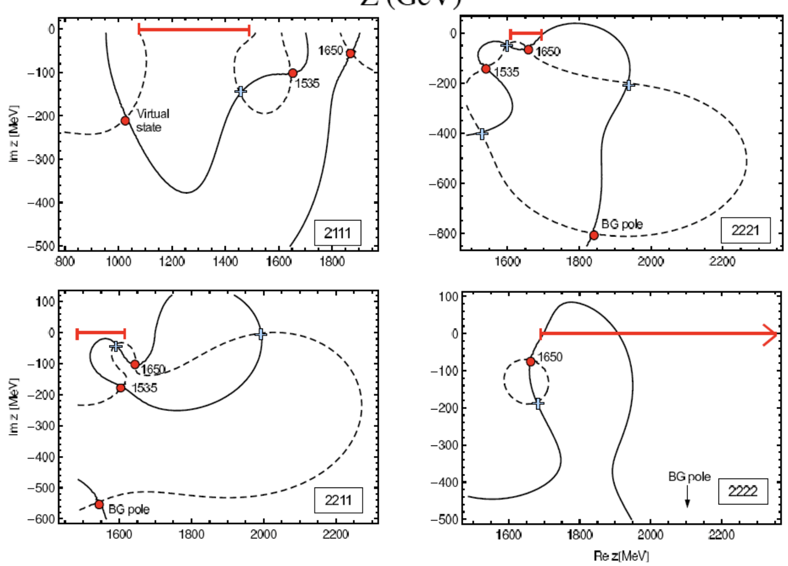


Example: *Poles & Shape of the S_{11} πN amplitude*

(Doring & Nakayama, EPJA'10)

Re[S_{11}] πN ampl.





.... virtual state on sheet 2111

---- hidden N*(1535) & N*(1650)

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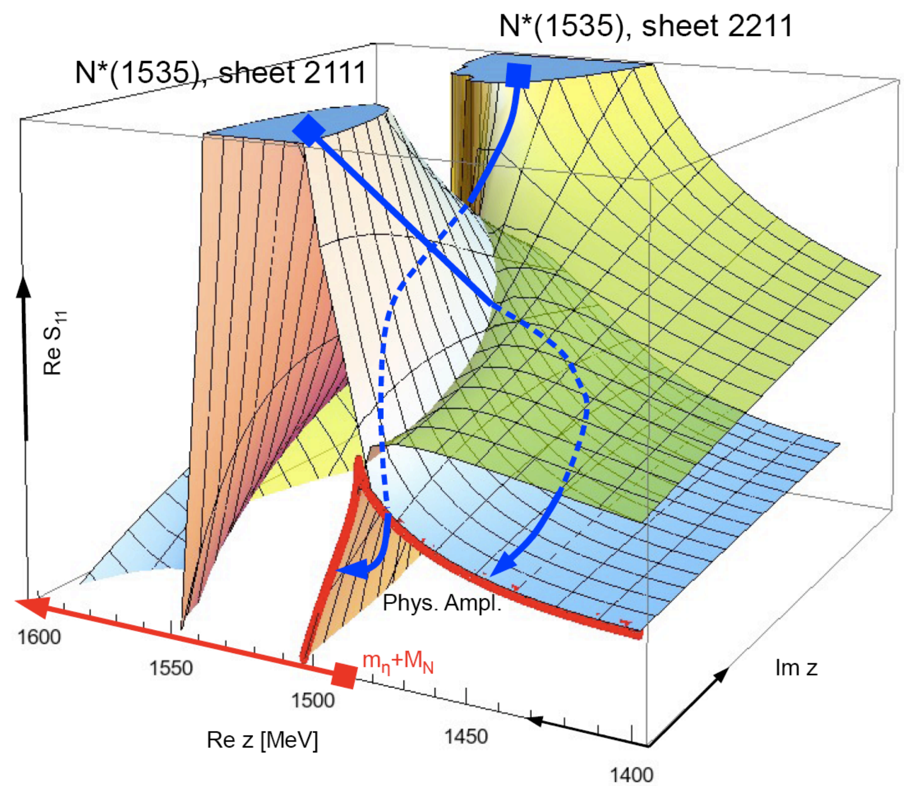


Example: *Complex branch point & Shape of the P_{11} πN amplitude*

(Ceci et al., arXiv:1104.3490)

δT = analytic continuation of Im[T]

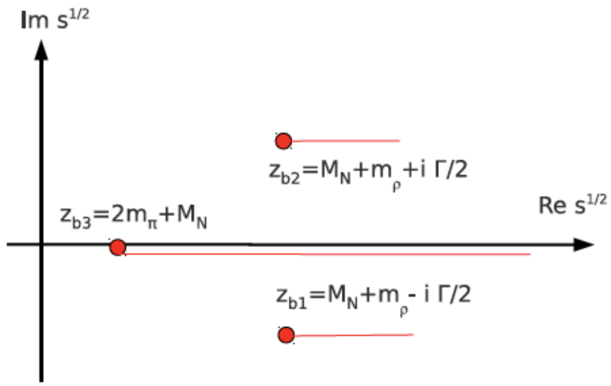


FIG. 2: Analytic structure of the amplitude. There are three branch points z_{b1}, $z_{b2} = z_{b1}^*$, and z_{b3}. z_{b1} and z_{b2} are structures in δT and thus on the second sheet.

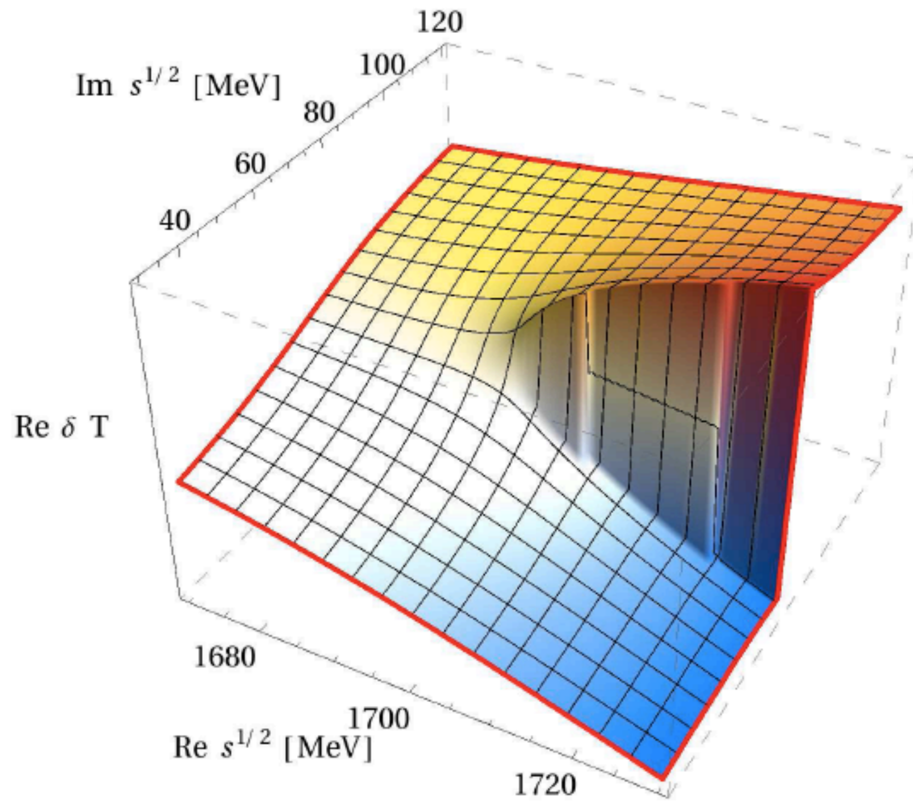


FIG. 3: Branch point z_{b2} in Re δT in the upper $\sqrt{s}$ half plane, for a realistic ρN intermediate state. The cut is chosen here in the positive Re $\sqrt{s}$ direction.

Basic question:

- physical amplitudes are on the real axis
- resonances live in the complex energy-plane

➔ requires a model !

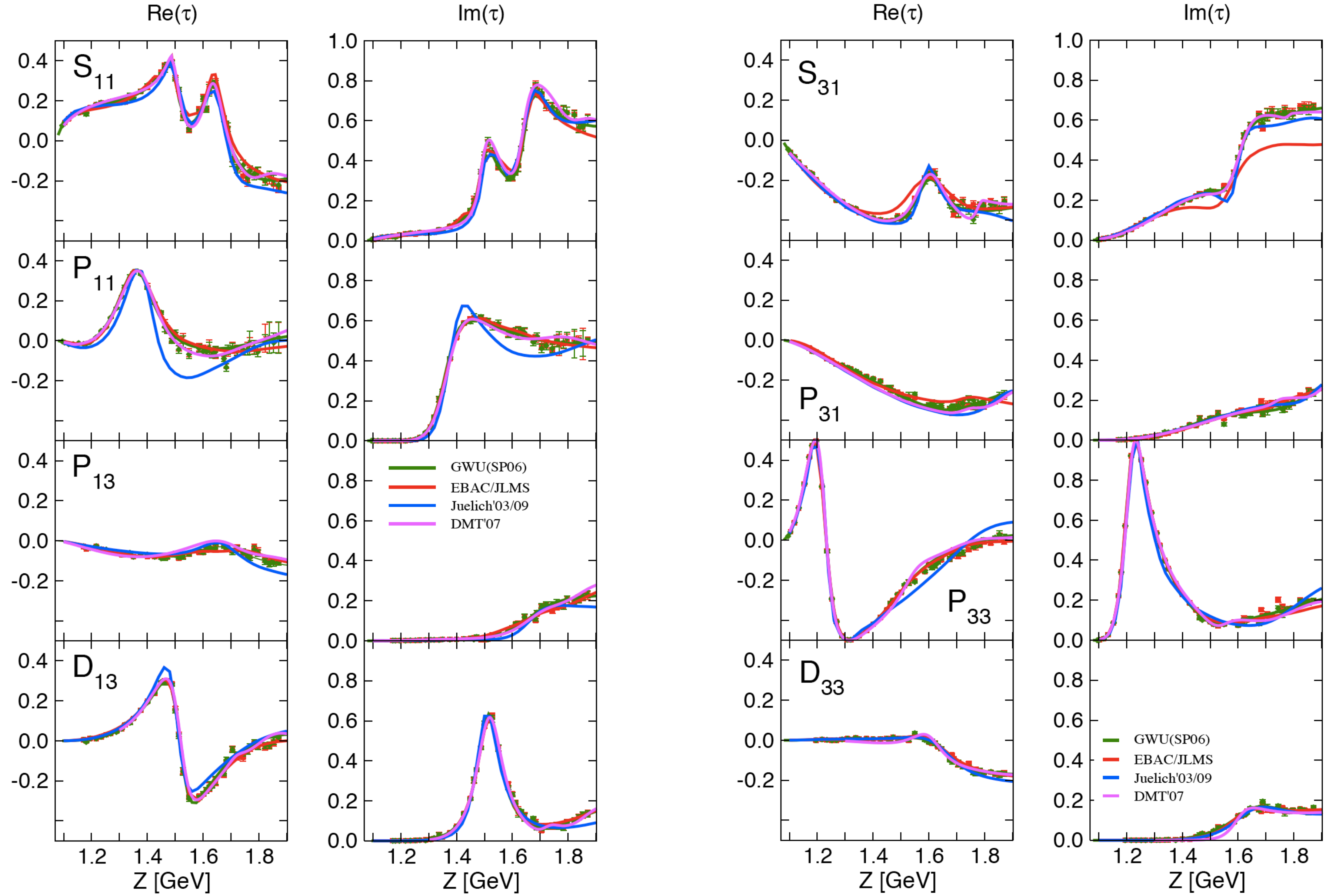
To which extend can the scattering data tells us about the actual existence of a resonance predicted by a model?

This question has an immediate consequence on baryon spectroscopy!

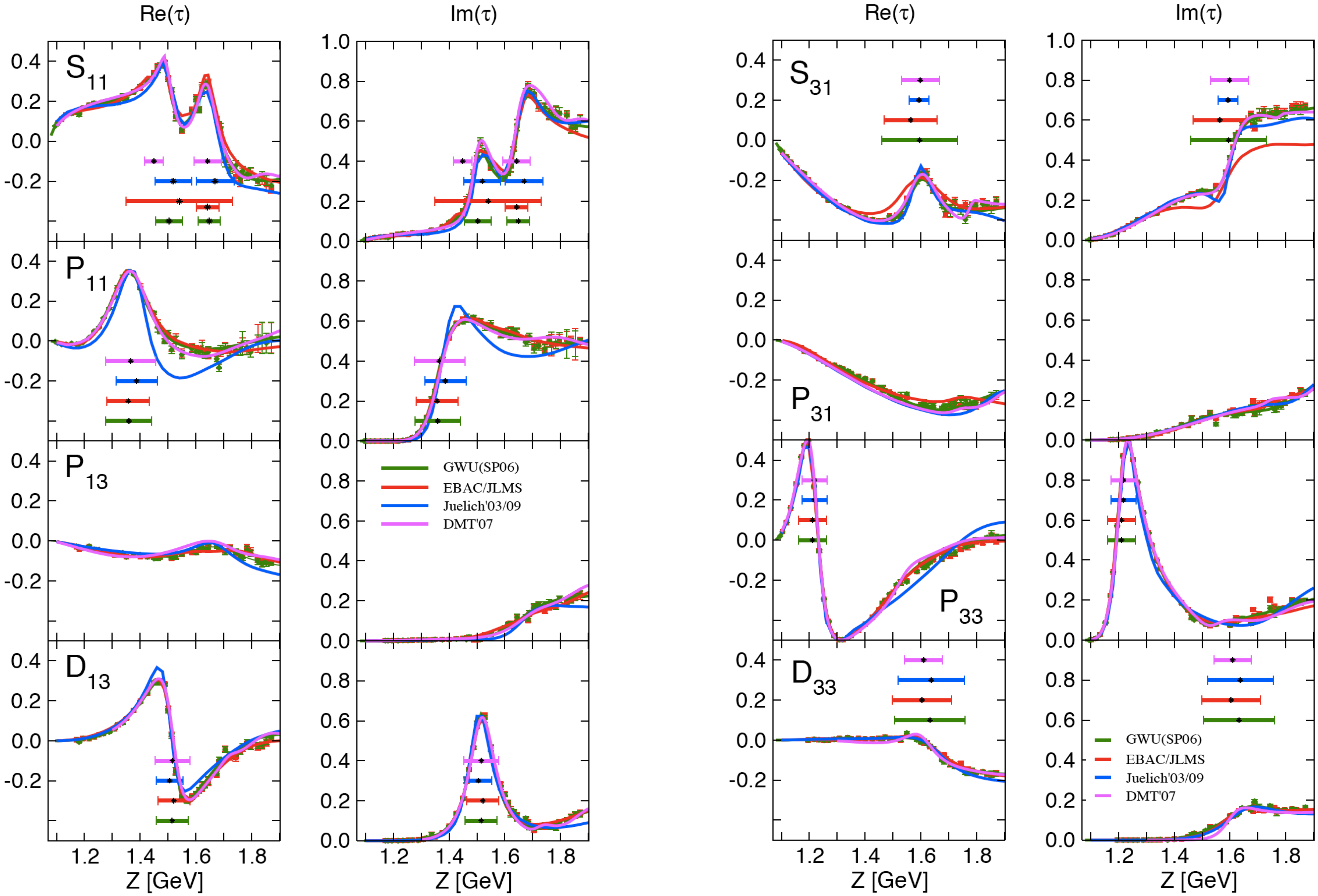
Models of analytic πN amplitudes:

Group	approach	channels	method	energy range (GeV)
Jülich'03/'09 (PRC68'03, NPA829'09)	DCM	πN, ηN, $\pi\Delta$, σN, ρN	TOPT	$z \leq 1.9$
EBAC/JLMS (PRC76'07, PRL104'10)	DCM	πN, ηN, $\pi\Delta$, σN, ρN	UT	$z \leq 2.0$
DMT'07 (PRC76'07)	DCM	πN, ηN, $\pi\pi N$(effectively)	3-D red. of BS	$z \leq 2.0$
GWU'06 (PRC74'06)	PWA constrained by (fixed-t) disp. relation	πN, ηN, $\pi\Delta$, ρN		$z \leq 2.6$
Jülich'11 (NPA851'11)	DCM ext. of Jülich'03/'09 (only isospin-3/2)	πN, ηN, $K\Sigma$ $\pi\Delta$, σN, ρN	TOPT	$z \leq 2.0$

$\pi N \to \pi N$ model comparison: τ-matrices



πN→πN model comparison: τ-matrices & poles



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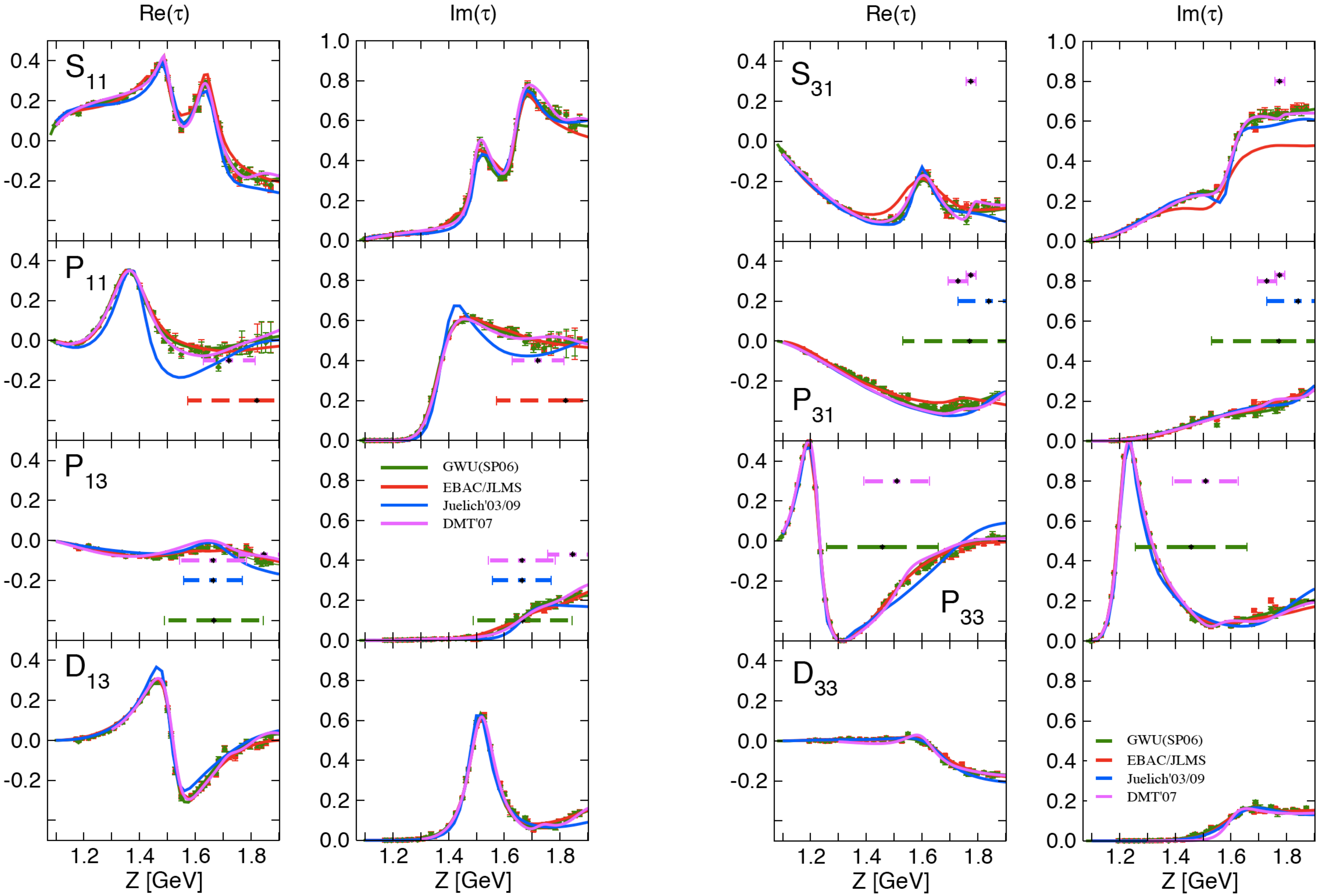
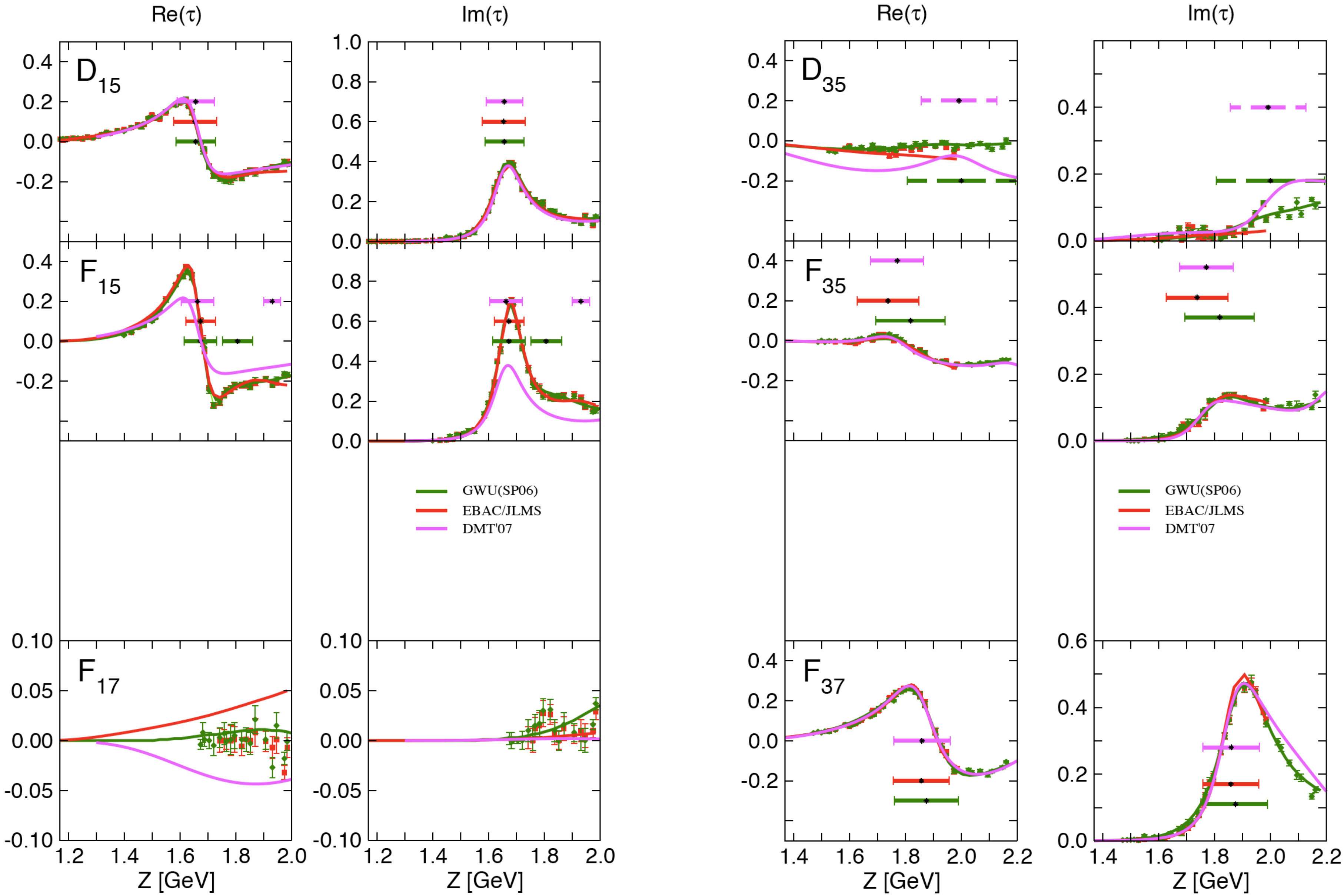
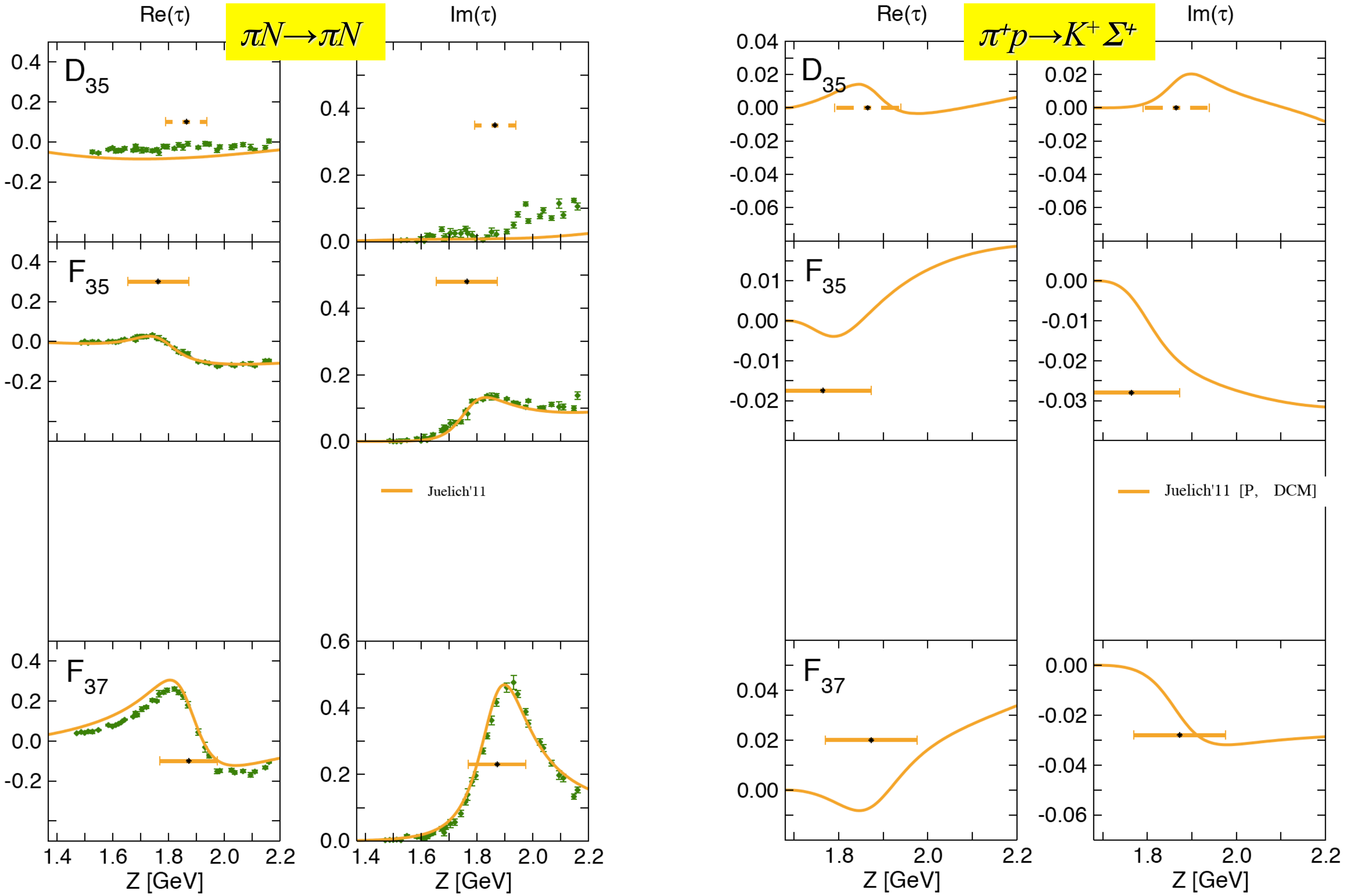


πN→ πN model comparison: *τ-matrices & poles*



$\pi^+ p \to K^+ \Sigma^+$ c.c. model: τ-matrices & poles

(Döring et al., NPA851'11)



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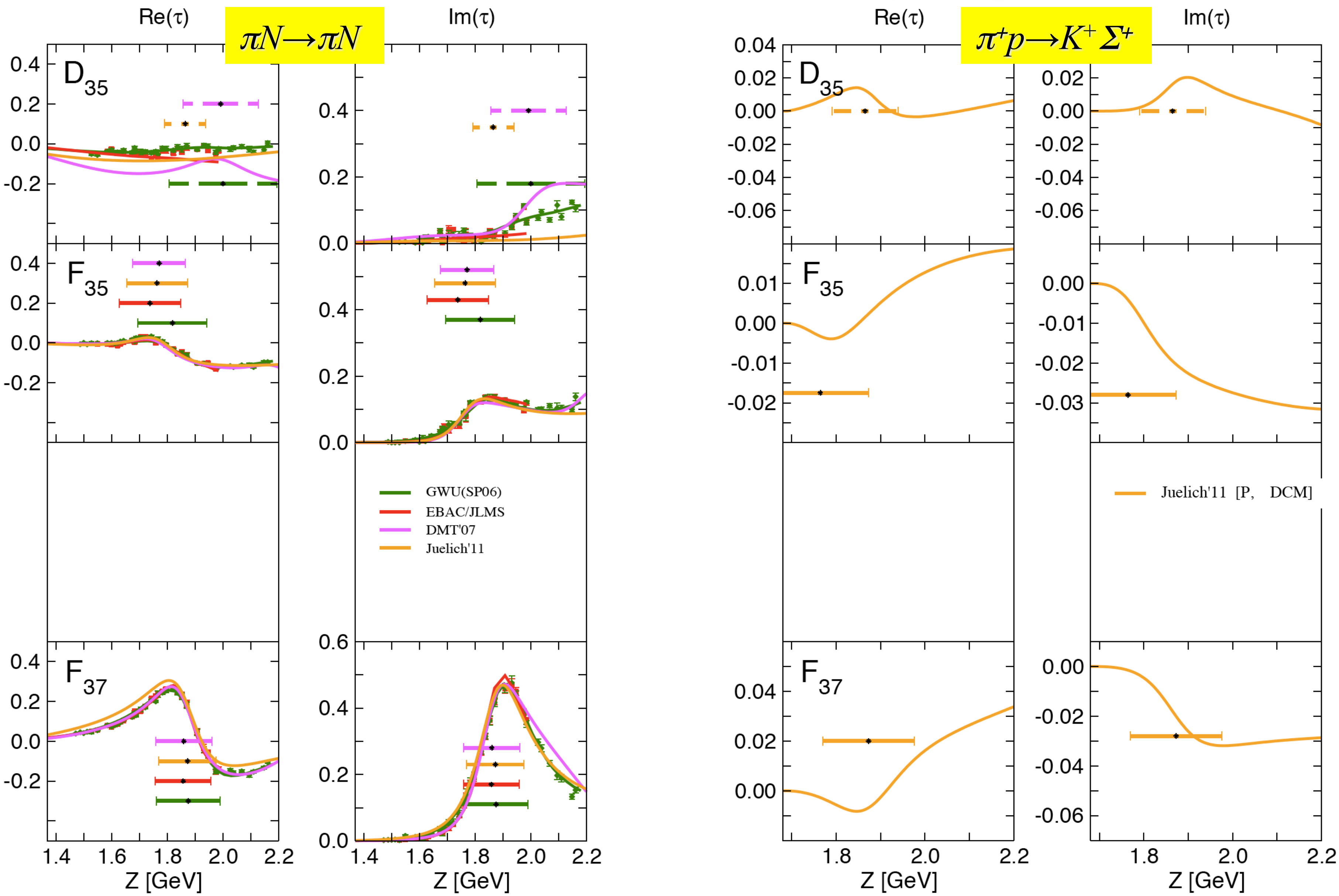

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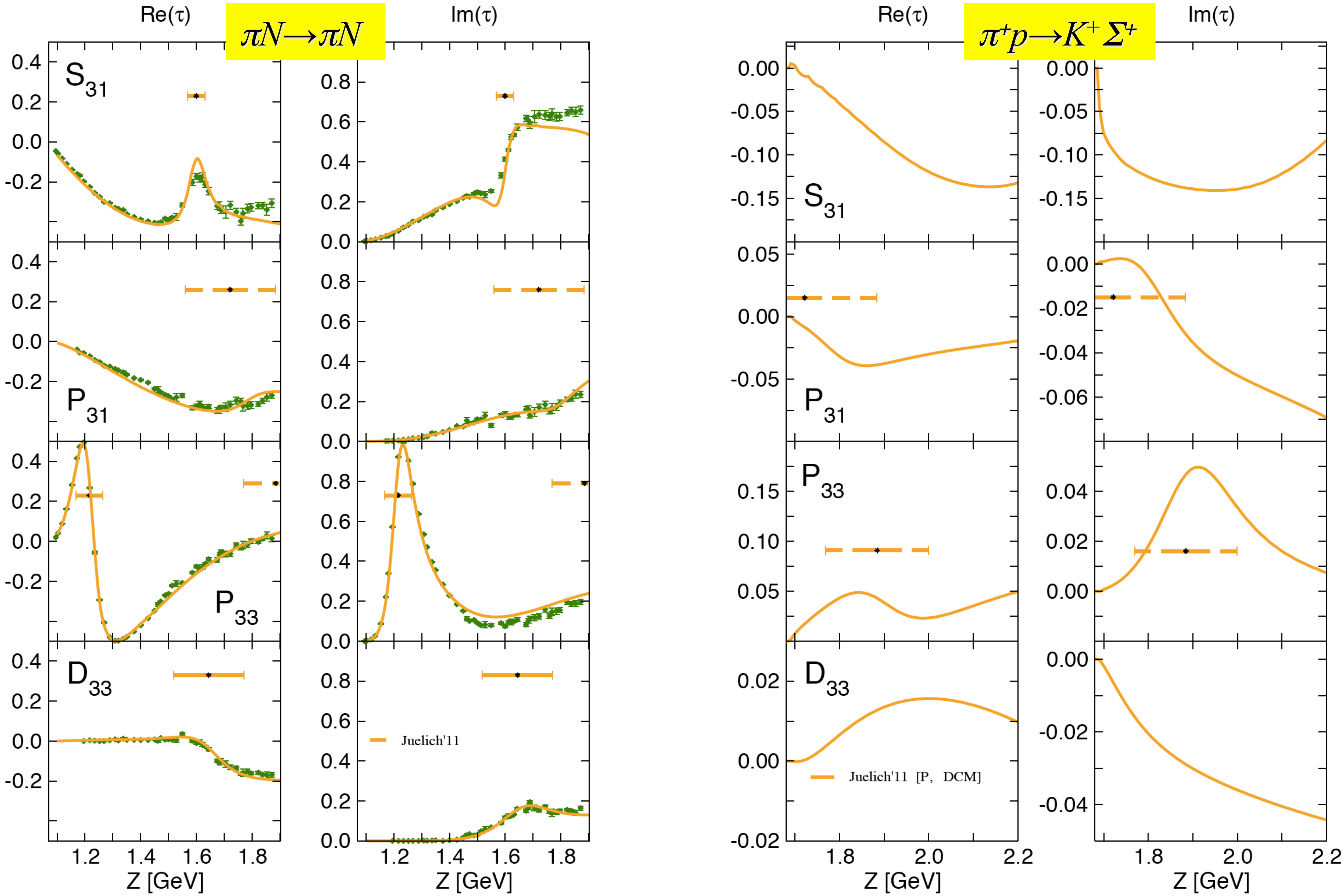

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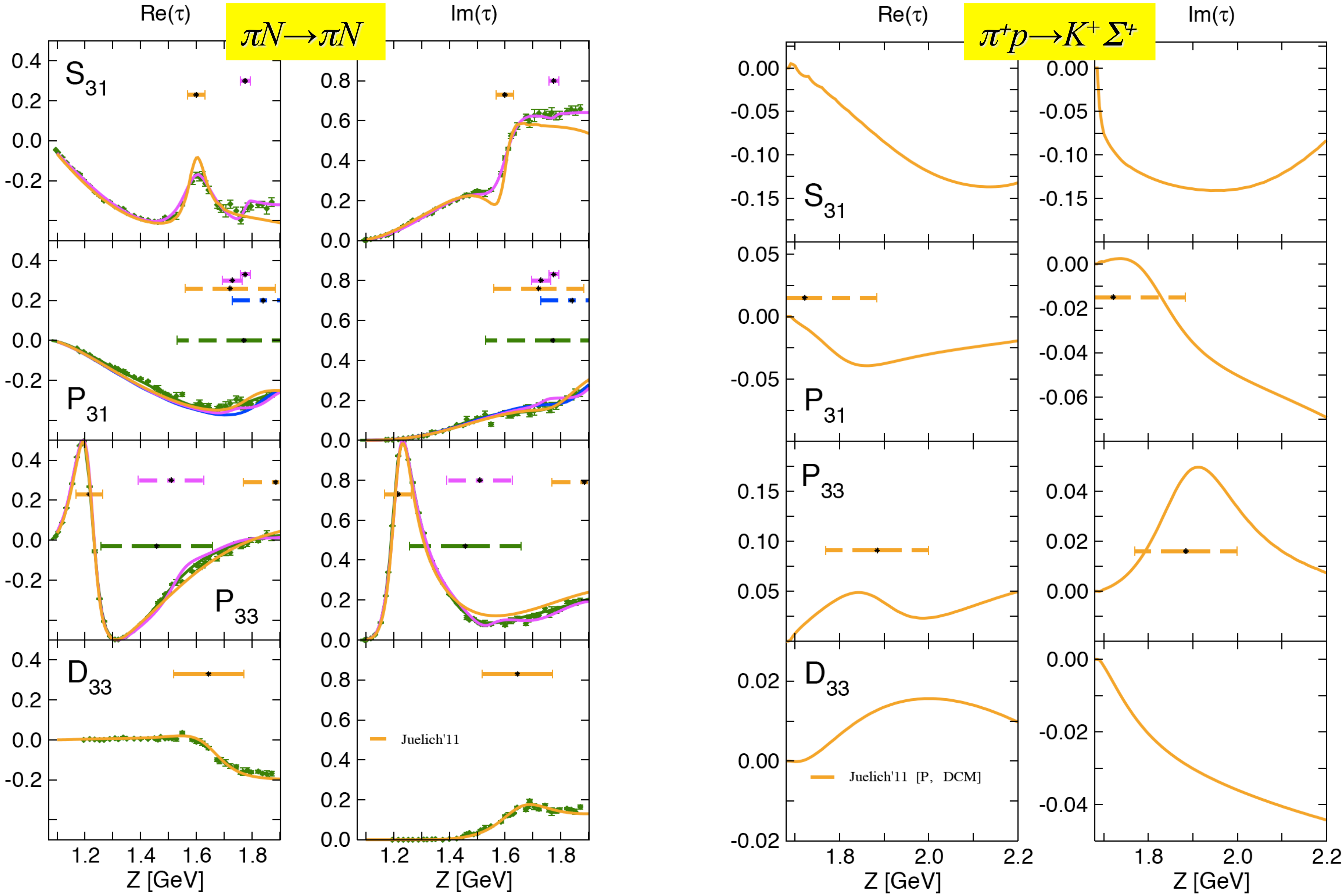

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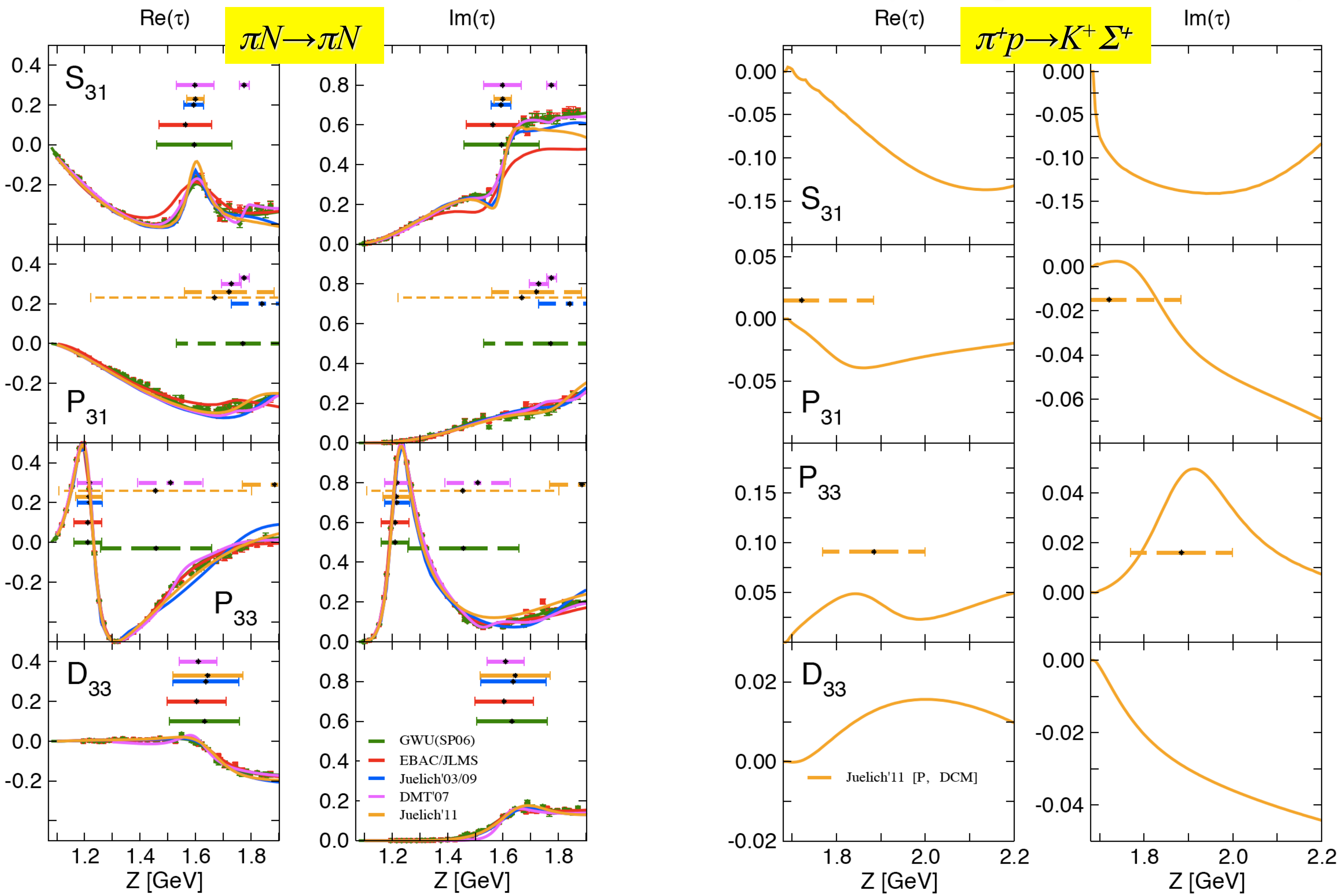

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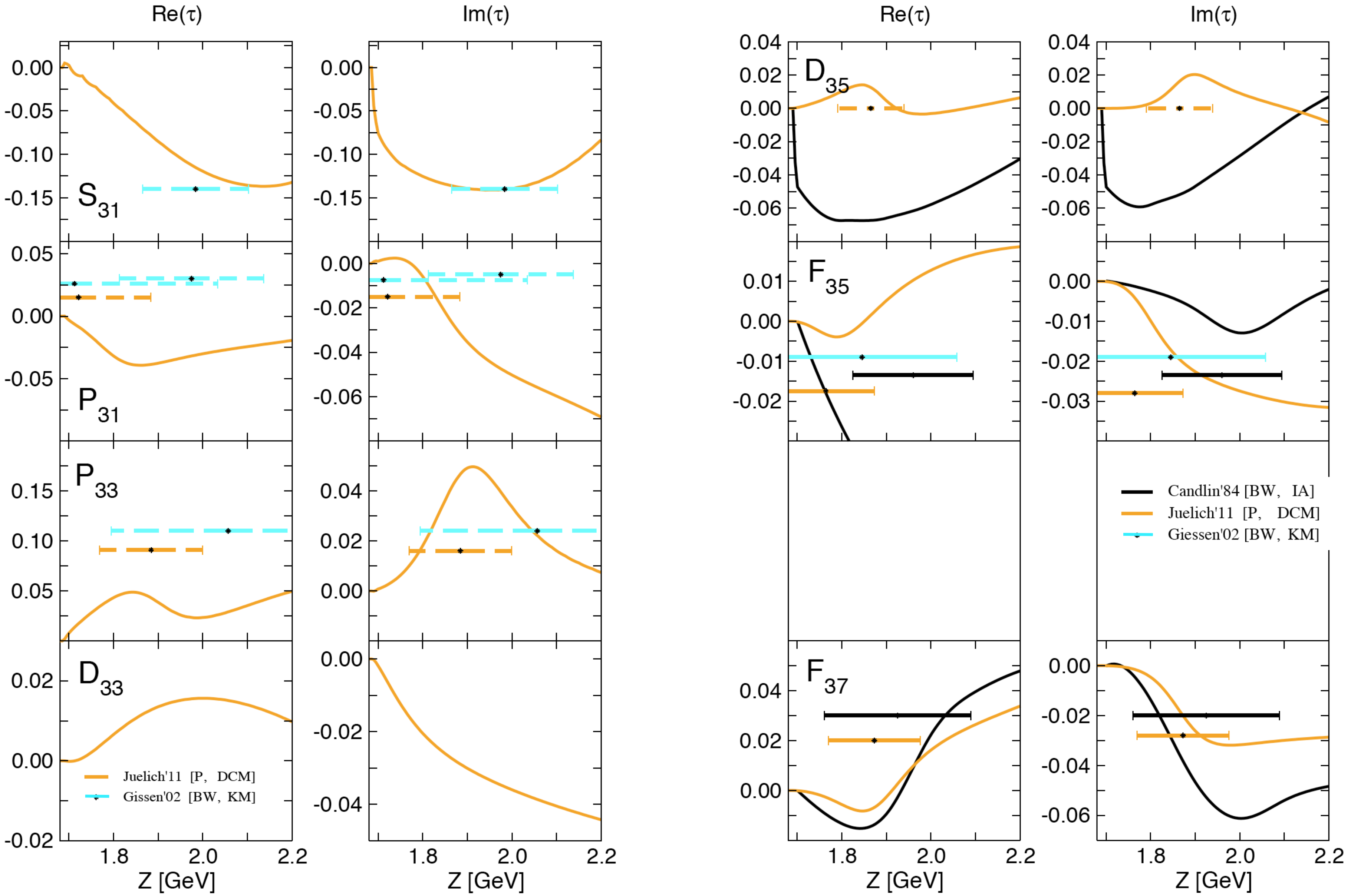

Conclusion:

- The existence of a resonance corresponding to a clear structure in the partial-wave amplitude is practically model-independent. Others are model-dependent.

  Resonance mass values of those corresponding to clear resonance structures are fairly model-independent and do not require a very high-precision fit of the amplitude. The widths, however, are more sensitive to particular models.

- A resonance whose existence is model-dependent, should be looked for in channels where they exhibit a clear structure in the corresponding partial-wave amplitude.

  This implies that coupled-channels analyses are crucial for establishing the existence of those resonances.

A possible way of establishing resonances:

1) A predicted resonance within a given model should be checked whether or not it corresponds to a clear structure in the corresponding partial-wave amplitude from that model. If yes, it should be confirmed by other independent models, i.e., the other models should also predict this resonance and it should also correspond to a clear structure in the partial-wave amplitude from those models.

2) For a predicted resonance not corresponding to a clear structure in the partial-wave amplitude in a given MN channel, it should be looked for in other channels where a clear structure can be found.

The End